# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

## 3.1 INTRODUCTION

This document details the market and technology assessment that the U.S. Department of Energy (DOE) has carried out in support of the ongoing energy conservation standards rulemakings for commercial refrigeration equipment (CRE), including commercial ice-cream freezers; self-contained commercial refrigerators, commercial freezers, and commercial refrigerator-freezers without doors; and remote condensing commercial refrigerators, commercial freezers, and commercial refrigerator-freezers. These rulemakings are mandated by the Energy Policy Act of 2005 (EPACT 2005), and are effective for equipment manufactured on or after January 1, 2012.

This chapter consists of two sections: the market assessment and the technology assessment. The goal of the market assessment is to develop a qualitative and quantitative characterization of the CRE industry and market structure based on publicly available information and data and information submitted by manufacturers and other stakeholders. Issues that are addressed include manufacturer characteristics and market shares, existing regulatory and non-regulatory efficiency improvement initiatives, equipment classes, and trends in markets and equipment characteristics. The goal of the technology assessment is to develop a preliminary list of technologies that could be used to improve the efficiency of commercial refrigeration equipment.

Commercial refrigeration equipment is used primarily to store and display perishable food products for sale in food-sales buildings (e.g., supermarkets and convenience stores), some multi-line retail stores, and in some food service applications like restaurants, salad bars, and cafeterias. The vast majority of equipment covered under this rulemaking, however, appears to be used in food-sales buildings. Food-sales buildings represent about 1.75 percent (1.26 billion square feet) of the commercial floor space in the United States and 4.87 percent (668 trillion British thermal units per year (Btu/yr)) of the total energy consumption attributed to the commercial sector.[a] Fully 5.84 percent (61 terawatt hours per year (TWh/yr)) of the electrical consumption in commercial buildings is attributed to food-sales buildings.[1] The high energy-use intensity of food-sales buildings is largely a product of the extensive use of commercial refrigeration equipment.

### 3.1.1 Definitions

Section 136(c) of EPACT 2005 amended section 342 of the Energy Policy Conservation Act (EPCA or the Act) to include new subsection (c)(4)(A) (42 U.S.C. 6313(c)(4)(A)), which mandates that DOE issue by rule, no later than January 1, 2009, energy conservation standards for the following equipment, manufactured on or after January 1, 2012: commercial ice-cream freezers; self-contained commercial refrigerators, commercial freezers, and commercial refrigerator-freezers without doors; and remote condensing commercial refrigerators, commercial freezers, and commercial refrigerator-freezers.

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[a] The values indicated are source energy values.

Section 136(a)(3) of EPACT 2005 amended section 340 of EPCA, in part by adding subsection 340(9) (42 U.S.C 6311(9)) with definitions for the following terms that describe commercial refrigeration equipment:

> "(9)(A) The term 'commercial refrigerator, freezer, and refrigerator-freezer' means refrigeration equipment that—
> (i) is not a consumer product (as defined in section 321);
> (ii) is not designed and marketed exclusively for medical, scientific, or research purposes;
> (iii) operates at a chilled, frozen, combination chilled and frozen, or variable temperature;
> (iv) displays or stores merchandise and other perishable materials horizontally, semivertically, or vertically;
> (v) has transparent or solid doors, sliding or hinged doors, a combination of hinged, sliding, transparent, or solid doors, or no doors;
> (vi) is designed for pull-down temperature applications or holding temperature applications; and
> (vii) is connected to a self-contained condensing unit or to a remote condensing unit.
>
> (B) The term 'holding temperature application' means a use of commercial refrigeration equipment other than a pull-down temperature application, except a blast chiller or freezer.
> * * *
> (D) The term 'pull-down temperature application' means a commercial refrigerator with doors that, when fully loaded with 12 ounce beverage cans at 90 degrees F, can cool those beverages to an average stable temperature of 38 degrees F in 12 hours or less.
> (E) The term 'remote condensing unit' means a factory-made assembly of refrigerating components designed to compress and liquefy a specific refrigerant that is remotely located from the refrigerated equipment and consists of one or more refrigerant compressors, refrigerant condensers, condenser fans and motors, and factory supplied accessories.
> (F) The term 'self-contained condensing unit' means a factory-made assembly of refrigerating components designed to compress and liquefy a specific refrigerant that is an integral part of the refrigerated equipment and consists of one or more refrigerant compressors, refrigerant condensers, condenser fans and motors, and factory supplied accessories."

EPACT 2005 does not explicitly define the terms "self-contained commercial refrigerator, freezer, or refrigerator-freezer" and "remote condensing commercial refrigerator, freezer, or refrigerator-freezer," which delineate two of the categories of equipment covered by this rulemaking. DOE construes these two terms to mean "commercial refrigerator, freezer, or refrigerator-freezer that is connected to a self-contained condensing unit" and "commercial refrigerator, freezer, or refrigerator-freezer that is connected to a remote condensing unit," respectively.

Accordingly, the three categories of equipment covered under this rulemaking are:

1. **Remote condensing commercial refrigerators, commercial freezers, and commercial refrigerator-freezers:** Under EPCA, this equipment includes commercial refrigerators, commercial freezers, and commercial refrigerator-freezers that have a remote condensing unit, except for any remote condensing equipment that would meet DOE's definition of "ice-cream freezer" as set forth at 10 CFR 431.62, 71 FR 71369. They are typically used to store and display products for direct sale to the consumer, and are referred to as "refrigerated display cases," "display cabinets," or "merchandisers." The remote condensing unit has at least one compressor and a condenser coil, and most are connected to a remote condensing unit that consists of multiple compressors (a compressor "rack") that serves multiple display cases.

2. **Self-contained commercial refrigerators, commercial freezers, and commercial refrigerator-freezers without doors**: Under EPCA, this equipment includes all types of commercial refrigerators, commercial freezers, and commercial refrigerator-freezers that have a self-contained condensing unit and have no doors, except for self-contained commercial equipment that meets DOE's definition of "ice-cream freezer" as set forth at 10 CFR 431.62, 71 FR 71369. As with remote condensing equipment, they are typically used to store and display products for direct sale to the consumer, and are commonly referred to as "refrigerated display cases," "display cabinets," or "merchandisers." Self-contained equipment is defined as having an integral condensing unit (i.e., the condensing unit is not remote from the refrigerated cabinet). (See 42 U.S.C. 6311(9)(F), added by EPACT 2005, section 136(a)(3).) The 2006 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) *Refrigeration Handbook* (chapter 47, p. 47.1) defines "reach-in" refrigerators or freezers as being upright and box shaped, and having hinged or sliding doors. Given this definition, self-contained reach-in commercial refrigerators, commercial freezers, and commercial refrigerator-freezers (i.e., self-contained equipment with doors) are not covered in this rulemaking because the rulemaking only covers self-contained equipment without doors.

3. **Commercial ice-cream freezers:** The EPCA provision that requires this rulemaking identifies "ice-cream freezers" separately from "self-contained commercial refrigerators, freezers, and refrigerator-freezers without doors" and "remote condensing commercial refrigerators, freezers, and refrigerator-freezers." (42 U.S.C. 6313(c)(4)(A), added by EPACT 2005, section 136(c)) The Act neither specifies nor indicates that "ice-cream freezers" are limited to equipment with a particular door configuration (e.g., with or without doors) or type of condensing unit (i.e., remote or self-contained). Thus, pursuant to EPCA's definition of "commercial refrigerator, freezer, and refrigerator-freezer" (42 U.S.C. 6311(9)(A), added by EPACT 2005, section 136(a)(3)), DOE believes commercial ice-cream freezers include equipment with all door types (i.e., solid doors, transparent doors, or no doors) and configurations (e.g., vertical or horizontal), as well as equipment with either integral or remote condensing units (i.e., self-contained or remote condensing).

On December 8, 2006, DOE published a final rule, in which it adopted test procedures for commercial refrigeration equipment. In this final rule, DOE adopted the following definition for "ice-cream freezer:" "a commercial freezer that is designed to operate at or below -5°F (-21°C) and that the manufacturer designs, markets, or intends for the storing, displaying, or dispensing of ice cream." 10 CFR 431.62, 71 FR 71369. In addition, this final rule prescribed the rating temperature at -15°F for ice-cream freezers. 10 CFR 431.64, 71 FR 71370.

## 3.2 MARKET ASSESSMENT

The following market assessment identifies the manufacturer trade association, domestic manufacturers of commercial refrigeration equipment, manufacturer market share, regulatory programs, and non-regulatory initiatives; defines equipment classes; provides historical shipment data, shipment projections, and equipment lifetime estimates; and summarizes market performance data.

### 3.2.1 Trade Association

The Air-Conditioning and Refrigeration Institute (ARI) is the trade association of commercial refrigeration equipment manufacturers. On January 12, 2005, ARI developed an agreement with manufacturers to establish the commercial refrigerator manufacturers division (CRMD) within ARI as well as develop and implement a certification program for commercial refrigerators, commercial freezers, and commercial refrigerator-freezers.

The CRMD was originally a separate trade organization founded in 1933. The industry it serves includes supermarkets, food stores, convenience stores, restaurants, hotels, motels, food processing establishments, and hospitals. The technical activities of CRMD include:

- Harmonization of international equipment standards;
- Development of industry performance standards for commercial refrigeration equipment;
- Updating of industry guidelines for retail store fixture installation, design, energy conservation, electronic case controls, and specifications for equipment installation;
- Maintaining liaison with refrigerant suppliers and government agencies on environmentally acceptable chlorofluorocarbon (CFC) alternatives; and
- Providing input to government agencies concerning regulations affecting the industry.

### 3.2.2 Manufacturers and Market Share

Current ARI CRMD members are shown in Table 3.2.1, with parent companies shown in parentheses, if applicable.

**Table 3.2.1 Commercial Refrigeration Manufacturers Division Members**

| | | |
|---|---|---|
| Barker Company | Hussmann (Ingersoll Rand) | Spartan Showcase |
| Beverage-Air | Killion Industries | Structural Concepts Corp. |
| Columbus Showcase Co. | Kysor/Warren (Enodis) | Tyler Refrigeration (Carrier, United Technologies Corp.) |
| Continental Refrigerator | Master-Bilt Products (Standex) | Zero Zone |
| Federal Industries (Standex) | McCall Refrigeration | |
| Hill Phoenix (Dover Corp.) | Southern Store Fixtures | |

Source: CRMD manufacturers listed as of November 2006, http://www.ari.org/sections/section_groups/CommercialRefrigerator/manufacturers.htm.

Non-ARI member commercial refrigeration equipment manufacturers are shown in Table 3.2.2, with parent companies shown in parentheses, if applicable.

**Table 3.2.2 Non-Air-Conditioning and Refrigeration Institute Member Commercial Refrigerator Manufacturers**

| | | |
|---|---|---|
| Amteko* | Howard/McCray | Silver King* |
| Arctic Air | Kelvinator | True Manufacturing* |
| Arctic Star* | McCray* | Turbo Air |
| Arneg USA* | Refcon* | Vogel* |
| Custom Deli* | Regan-Pinnacle | |
| Custom Fabricators* | Royal Store Fixtures (Parisi)* | |

*Based on ARI comment submitted to the Framework Document (ARI, No. 7 Exhibit A at p. 1)[b] with the addition of Silver King.[2]

The following provides a brief listing of the manufacturers that produce self-contained commercial refrigeration equipment without doors, remote condensing commercial refrigeration equipment, and commercial ice-cream freezers.

The majority of the domestic market share of self-contained and remote condensing commercial refrigeration equipment without doors is held by five major manufacturers. These manufacturers are listed below, with their parent companies in parentheses, if applicable.[3]

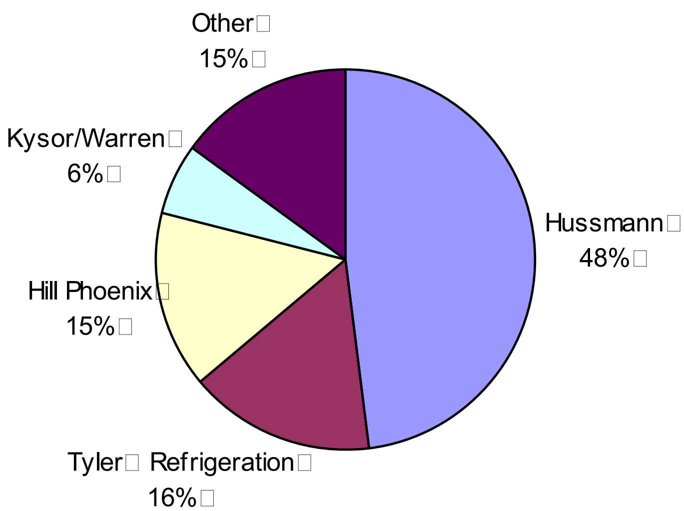
- Hill Phoenix (Dover Corporation)
- Hussmann Corporation (Ingersoll Rand)
- Kysor/Warren (Enodis)
- Tyler Refrigeration (Carrier, United Technologies Corporation)
- Zero Zone

[b] A notation in the form "ARI, No. 7 Exhibit A at p. 1" identifies a written comment DOE has received and has included in the docket of this rulemaking. This particular notation refers to a comment (1) by the Air-Conditioning and Refrigeration Institute (ARI), (2) in document number 7 Exhibit A in the docket of this rulemaking (maintained in the Resource Room of the Building Technologies Program), and (3) appearing on page 1 of document number 7 Exhibit A.

Although the above information applies to both self-contained and remote condensing commercial refrigeration equipment without doors, only the self-contained refrigeration equipment without doors is applicable under this rulemaking. True Manufacturing also manufactures self-contained commercial equipment and has a large share of shipments of self-contained commercial equipment without doors and commercial ice-cream freezers.

According to *Appliance Magazine*, four companies represent approximately 85 percent of the U.S. “refrigerated display case” market with approximately 185,000 units shipped in 2004.[4] Although *Appliance Magazine* describes the data as “refrigerated display cases,” no precise definition of refrigerated display case is provided and is therefore unclear as to what specific types of equipment it covers–equipment that is self-contained versus remote condensing and equipment with doors versus without doors. Only the self-contained equipment without doors and remote condensing equipment are applicable under this rulemaking.

As of 2004, Hussmann Corporation, a division of Ingersoll Rand, was the largest domestic manufacturer, holding approximately 48 percent of the U.S. refrigerated display case market. Like most industries, there exists a second tier of smaller but well-known manufacturers. These other manufacturers make up the remaining 15 percent of U.S. market share. Figure 3.2.1 illustrates the market share breakdown in the United States refrigerated display case industry.




Source: *Appliance Magazine*, *28th Annual Portrait of the U.S. Appliance Industry*, September 2005.

**Figure 3.2.1 Domestic Refrigerated Display Case Market Shares**

Companies considered within the “Other” category are listed in Table 3.2.3, with parent companies in parentheses, if applicable. Manufacturers of commercial ice-cream freezers are listed in Table 3.2.4 with parent companies in parentheses, if applicable.

**Table 3.2.3 "Other" Domestic Refrigerated Display Case Manufacturers**

| | | |
|---|---|---|
| Arneg USA | Killion Industries | True Manufacturing |
| Barker Company | Master-Bilt Products (Standex) | Turbo Air |
| Columbus Showcase Co. | Royal Store Fixture (Parisi) | Zero Zone |
| Federal Industries (Standex) | Southern Store Fixtures | |
| Howard/McCray | Structural Concepts Corp. | |

Source: *Appliance Magazine*, *28th Annual Portrait of the U.S. Appliance Industry*, September 2005.

**Table 3.2.4 Commercial Ice-Cream Freezer Manufacturers**

| | | |
|---|---|---|
| Arctic Air | Hussmann (Ingersoll Rand)* | Structural Concepts Corp.* |
| Beverage-Air* | Kelvinator | True Manufacturing |
| Columbus Showcase Co.* | Kysor/Warren (Enodis)* | Tyler Refrigeration (Carrier, United TechnologiesCorp.)* |
| Continental Refrigerator* | Master-Bilt Products (Standex)* | Zero Zone* |
| Delfield (Enodis) | McCall Refrigeration* | |
| Hill Phoenix (Dover Corp.)* | Silver King | |

* Based on ARI comment submitted to the Framework Document (ARI, No. 7 Exhibit A at p. 1).

### 3.2.2.1 Small Businesses

DOE is considering the possibility that small businesses would be particularly impacted by the promulgation of energy conservation standards for commercial refrigeration equipment. The Small Business Administration (SBA) defines small business manufacturing enterprises for commercial refrigeration equipment as those having 750 employees or fewer.[5] SBA lists small business size standards for industries as they are described in the North American Industry Classification System (NAICS). The size standard for an industry is the largest that a for-profit concern can be in that industry and still qualify as a small business for Federal Government programs. These size standards are generally expressed in terms of the average annual receipts or the average employment of a firm. For commercial refrigeration equipment, the size standard is matched to NAICS code 333415, Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing, and is 750 employees.

DOE will study the potential impacts on these small businesses in detail during the manufacturer impact analysis, which will be conducted as a part of the notice of proposed rulemaking analysis. Table 3.2.5 lists the small business commercial refrigeration equipment manufacturers that DOE has identified.

**Table 3.2.5 Small Business Manufacturers of Commercial Refrigeration Equipment**

| | | |
|---|---|---|
| Barker Company | Royal Store Fixture (Parisi) | Structural Concepts Corp. |
| Columbus Showcase Co. | Regal-Pinnacle | Turbo Air |
| Killion Industries | Southern Store Fixtures | Zero Zone |

### 3.2.3 Regulatory Programs

Both Canada and the State of California have efficiency standards in place for commercial ice-cream freezers but not for the other equipment covered in this rulemaking (i.e., remote condensing commercial equipment and self-contained commercial equipment without doors). In the case of remote condensing equipment, the Canadian Standards Association (CSA) has established efficiency standards as part of its overall test standards. Australia has several efficiency standards in place for all of the equipment covered in this rulemaking.

The following States have established appliance efficiency regulations: Arizona, California, Connecticut, Maryland, Massachusetts, Minnesota, New Jersey, New York, Oregon, Rhode Island, Vermont, and Washington. Of these, California is the only State that explicitly regulates equipment covered in this rulemaking–commercial ice cream freezers and remote condensing equipment with transparent doors.

Minnesota and Vermont do not regulate commercial refrigeration equipment at all. Arizona, Oregon, Rhode Island, and Washington regulate certain types of commercial refrigeration equipment. However, these States specifically exclude commercial ice-cream freezers, remote condensing commercial equipment and self-contained commercial equipment without doors.

Connecticut, Maryland, Massachusetts, New Jersey, and New York regulate certain commercial refrigeration equipment, but make no mention of commercial ice-cream freezers. Connecticut and Maryland also make no mention of remote condensing commercial equipment or self-contained commercial equipment without doors. New York and Maryland legislation does not include remote condensing commercial equipment and self-contained commercial equipment without doors. New Jersey makes no mention of remote condensing commercial equipment, but does include self-contained commercial equipment without doors. However, no standards are currently in place for this equipment.

#### 3.2.3.1 California

California Energy Commission (CEC) Appliance Efficiency Regulations (effective July 1, 2006) establish efficiency standards for commercial ice-cream freezers, but not for the other types of equipment covered in this rulemaking (i.e., remote condensing commercial equipment and self-contained commercial equipment without doors). The maximum allowed daily energy consumption (kilowatt hours (kWh) per day) for commercial ice-cream freezers vary based on the door type (i.e., solid or transparent) and volume (V). There are two different standard levels with two different effective dates of January 1, 2006 and January 1, 2007 as shown in Table 3.2.6.

**Table 3.2.6 California Energy Commission Efficiency Regulations for Commercial Ice-Cream Freezers**

| Equipment Type | Type of Door | Maximum Daily Energy Consumption [kWh] Effective January 1, 2006 | Maximum Daily Energy Consumption [kWh] Effective January 1, 2007 |
|---|---|---|---|
| Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are ice-cream freezers | Solid | 0.398 V + 2.28 | 0.39 V + 0.82 |
| | Transparent | 0.940 V + 5.10 | 0.88 V + 0.33 |

V = Volume in $ft^3$
Source: Appliance Efficiency Regulations, July 2006, CEC-400-2006-002-REV1, section 1605.3, Table A-7.

The CEC regulations also have a design requirement for lighting in remote condensing commercial equipment with transparent doors, self-contained commercial equipment without doors, and remote condensing commercial equipment without doors. This design requirement mandates that the internal illumination must be provided by T-8 fluorescent lamps with electronic ballasts or a lighting system that has no fewer lumens per watt than a system using only T-8 fluorescent lamps with electronic ballasts.[6] This requirement is valid for all equipment manufactured and/or sold in the State of California.

The test methods used for determining compliance with the CEC regulations are American National Standards Institute/Association of Home Appliance Manufacturers (ANSI/AHAM) HRF-1-1979, *Household Refrigerators, Combination Refrigerator-Freezers, and Household Freezers*, for volume measurements; ANSI/ASHRAE Standard 117-1992, *Method of Testing Closed Refrigerators,* for energy consumption measurements of self-contained commercial refrigerators, commercial freezers and commercial refrigerator-freezers with doors; and ANSI/ASHRAE Standard 72-1998, *Method of Testing Open Refrigerators*, for energy consumption measurements of self-contained commercial refrigerators, commercial freezers, and commercial refrigerator-freezers without doors. The energy consumption tests are conducted with the following integrated average product temperatures (IAT) (because the CEC standards for refrigerators and freezers are only for those equipment with doors and a self-contained condensing unit, only the IAT for commercial ice-cream freezers is germane here):

- Refrigerator Compartment: 38°F ± 2°F (3.3°C ± 1.1ºC)
- Freezer Compartment: 0°F ± 2°F (-17.8°C ± 1.1ºC)
- Wine Chiller: 45°F ± 2°F (7.2°C ± 1.1ºC)
- Ice-Cream Cabinet: -5°F ± 2°F (-20.6°C ± 1.1ºC)

### 3.2.3.2 Canada

The Natural Resources Canada (NRCan) Office of Energy Efficiency has energy efficiency standards for self-contained commercial "reach-in" refrigerators, freezers, and refrigerator-freezers with solid/opaque doors or transparent doors, and are based on California's regulations.[7] Because NRCan considers commercial ice-cream freezers a type of self-contained commercial "reach-in" freezer, these regulations apply to commercial ice-cream freezers.

The approach taken by Canada differs from that of California. The Canadian standards, rather than specifying the type of equipment covered, define commercial refrigerators, commercial freezers, and commercial refrigerator-freezers in a manner that identifies only those units that are *not* covered by standards. In addition, manufacturers of commercial refrigerators and commercial freezers without doors are required to report the rated energy use of the equipment, although the equipment does not have to meet any standard at this time. The test method for determining compliance is ANSI/ASHRAE Standard 117-1992, *Method of Testing Closed Refrigerators,* with the following specifications for the IAT:

- Refrigerator Compartment: 38°F ± 2°F (3.3ºC ± 1.1ºC)
- Freezer Compartment: 0°F ± 2°F (-17.8ºC ± 1.1ºC)
- Wine Chiller: 45°F ± 2°F (7.2ºC ± 1.1ºC)
- Ice-Cream Cabinet: -5°F ± 2°F (-20.6ºC ± 1.1ºC)

The two tiers of performance standards for self-contained commercial freezers (under which ice-cream freezers are classified) will take effect April 1, 2007 and January 1, 2008, respectively. As shown in Table 3.2.7 below, maximum daily energy consumption depends on door type and volume.

**Table 3.2.7 Canadian Efficiency Regulations for Commercial Ice-Cream Freezers**

| Equipment Type | Type of Door | Volume (V) [Liters] | Maximum Daily Energy Consumption (E) Effective April 1, 2007 [kWh] | Maximum Daily Energy Consumption (E) Effective January 1, 2008 [kWh] |
|---|---|---|---|---|
| Self-contained commercial freezers | Opaque | < 340 | E = 7.62 | E = 7.07 |
| | Opaque | ≥ 340 | E = 0.0141 V + 2.83 | E = 0.0141V + 2.28 |
| | Transparent | - | E = 0.0332 V + 5.10 | - |

Source: Amendment 9 to the Energy Efficiency Regulations published in Canada Gazette Part II, November 15, 2006.

#### 3.2.3.3 Canadian Standards Association

CSA is an independent standards-setting agency that establishes test procedures and efficiency standards that are typically adopted by the Canadian government. The Canadian standard CAN/CSA C657-04, *Energy Performance Standard for Refrigerated Display Cabinets (Merchandisers)*, applies to remote condensing commercial equipment with and without doors, and self-contained commercial equipment with and without doors, except as covered by CSA C827-98 (R2003). Commercial refrigerators and commercial freezers with doors (including commercial ice-cream freezers) are covered in a separate test procedure and standard, CSA C827-98 (R2003), *Energy Performance Standard for Food Service Refrigerators and Freezers*. This standard is a revision of the original CSA standard published in 1995. Among the changes are redefined equipment categories and new minimum energy performance standards (MEPS) (the changes to the standard make it extremely difficult to compare levels between the 1995 and updated standards).

The CSA C657-04 standard divides commercial refrigeration equipment into seven classes and several sub-classes. Classes and MEPS levels from CSA C657-04 are summarized in Table 3.2.8 below. For equipment with a remote condensing unit, the MEPS use a predetermined remote condensing unit efficiency to determine daily energy use.

**Table 3.2.8 Canadian Standards Association Equipment Classes and Efficiency Ratings**[8]

| Class | IAT* (°F) | Temperature | Open/Closed | Deck | Number of Air Curtains | Angle of Air Curtain from Vertical | MEPS 2004 *(kWh/ft per day)* |
|---|---|---|---|---|---|---|---|
| 1 | 41.0 | medium | open | single/multi | 1 | 0-30° | 4.0 |
| 2 | 41.0 | medium | open | single/multi | 1 | 30-60° | 2.9 |
| 3 | 41.0 | medium | open | single/multi | 1 | 60-90° | 1.6 |
| 4 | 0.0 | low | open | multi | 2 or 3 | 0-30° | 9.4 |
| 5 | 0.0 | low | open | single | 1 | 60-90° | 4.6 |
| 6a | 41.0 | low/medium | closed | multi | single vent with glass | | 2.3 |
| 6b | 0.0 | Same as 6a | | | | | 6.1 |
| 7a | 41.0 | medium | closed | single/multi | glass | n/a | 2.6 |
| 7b | 41.0 | Same as 7a, except with only a gravity coil (no fan coil) | | | | | 1.0 |

* IAT = the average temperature of all test packages as recorded during testing.
Source: CSA C657-04, *Energy Performance Standard for Refrigerated Display Cabinets (Merchandisers).*

#### 3.2.3.4 Australia

Australia has required efficiency standards for commercial refrigeration equipment as of October 1, 2004.[9] The standards apply to both remote condensing and self-contained commercial equipment primarily used for the storage of chilled and frozen food. The minimum energy performance standards are set out in Australian Standard (AS) 1731.14-2003 as total energy consumption per total display area (TEC/TDA) in kWh/day/meter$^2$ (m$^2$) for various equipment types. The Australian standards categorize equipment by the following criteria:

- Remote or self-contained condensing unit
- Lit shelves or unlit shelves
- Number of shelves
- Solid door or glass door
- Fan coil or gravity coil
- High, medium, or low temperature

The standards also specify minimum energy performance by M-package temperatures (temperature of a load package) for self-contained cabinets. The test procedures used to measure energy consumption are specified in AS 1731-2003.

### 3.2.4 Non-Regulatory Initiatives

DOE reviewed several voluntary programs promoting energy-efficient commercial refrigeration equipment in the United States, including the Environmental Protection Agency (EPA) ENERGY STAR program for solid-door commercial refrigerators and commercial freezers, the Consortium for Energy Efficiency (CEE)'s initiative for commercial refrigeration equipment, and the Federal Energy Management Program (FEMP)'s procurement program for energy-efficient commercial refrigerators and commercial freezers. DOE also reviewed various rebate programs offered by local utilities.

#### 3.2.4.1 ENERGY STAR

The EPA's ENERGY STAR labeling program has specifications for self-contained solid-door commercial refrigerators and commercial freezers, including commercial ice-cream freezers.[10] This program does not apply to remote condensing commercial equipment or self-contained commercial equipment without doors. To meet the ENERGY STAR criteria for commercial ice-cream freezers, the maximum energy consumption allowed is as follows:

- Maximum Energy Consumption $\leq 0.39V + 0.82$ kWh/day
  where V is the internal volume in cubic feet ($ft^3$).

The test method used in the ENERGY STAR program is the ANSI/ASHRAE Standard 117-1992, *Method of Testing Closed Refrigerators*. The energy consumption tests are conducted with an IAT of -5°F ± 2°F for commercial ice-cream freezers. The ENERGY STAR program has no explicit mention of a test method for the measurement of internal volume.

#### 3.2.4.2 Consortium for Energy Efficiency

The CEE has a Commercial Kitchen Initiative for solid door and glass-door reach-in commercial refrigerators and commercial freezers.[11] This program is based on ENERGY STAR levels and only applies to self-contained commercial equipment with doors and is therefore not relevant to this rulemaking. The program specifies standard levels in terms of maximum daily energy use in kWh/day for various door types.

#### 3.2.4.3 Federal Energy Management Program

FEMP has established purchasing specifications for energy-efficient equipment, including commercial ice-cream freezers.[12] Federal purchasers are now required by EPACT 2005 to purchase equipment that is ENERGY STAR-qualified or FEMP-designated. This equipment is in the upper 25 percent of energy efficiency in its class. The coverage of the FEMP program is identical to the ENERGY STAR program, and is therefore not relevant to this rulemaking.

#### 3.2.4.4 Rebate Programs

Several rebate programs for commercial refrigeration equipment are offered by local utilities, including Efficiency Vermont, the Energy Smart Grocer Program, the Nevada Sure Bet Program, Otter Tail Power Company, Roseville Electric, Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E).

Efficiency Vermont, an organization offering technical assistance and financial incentives to encourage energy efficiency in the State of Vermont, offers rebates for the installation of strip-curtain covers for commercial refrigeration equipment without doors. The cash incentive is $6 per foot of display case that is covered by the curtain.[13]

The Energy Smart Grocer Program is funded by California utility ratepayers under the auspices of the California Public Utilities Commission. Eligible participants include grocery and convenience stores, food processors, and refrigerated warehouses operating in PG&E, SCE, or SDG&E electric service territories. The program offers rebates for the use of night covers on commercial refrigeration equipment without doors, upgrades to more efficient case lighting, and the replacement of older equipment without doors with new high-efficiency equipment or new or refurbished reach-ins.[14]

Sierra Pacific Power and Nevada Power offer incentives promoting the installation of energy efficient commercial refrigeration equipment through the Nevada Sure Bet Program. These rebates are available to the utilities' commercial, industrial, and institutional customers. In addition to other refrigeration rebates, the program offers $4 per linear foot for the installation of night covers on commercial refrigeration equipment without doors.[15]

Otter Tail Power Company offers rebates to Minnesota commercial customers under the Conservation Improvement Program. Under this program, customers are eligible to receive between $10 and $20 per linear foot of, or upgrade to, high efficiency commercial refrigeration equipment.[16]

Roseville Electric has a "Custom" Rebate program, which includes commercial refrigeration equipment, in which the customer is paid for energy efficiency projects that reduce peak kW; however, no rebates are paid on kWh savings. In this type of rebate the customer, or their engineer, would present the project scope, including what equipment is currently installed, what is proposed, and how the proposed equipment goes beyond what would be considered standard for today's replacement. Engineering calculations would be provided to show kW and kWh savings. Roseville Electric would evaluate the customers' proposal and advise if the project is eligible for rebates and at what level. Typically these are paid at $400/kW, but may be less if significant third party engineering work is required to verify the peak load reductions.[17]

PG&E, SCE, and SDG&E offer rebates to business customers for retrofit refrigeration projects through the Express Efficiency Refrigeration Program. The program provides $9 per linear foot for night covers installed on existing commercial refrigeration equipment without doors to all business customers. The program also gives incentives for the installation of glass doors on existing equipment without doors. This rebate is applicable to both self-contained commercial equipment and remote condensing commercial equipment. The rebate provides $200 per door installed on an otherwise open low-temperature display case and $150 per door installed on a medium- temperature display case.[18, 19, 20]

### 3.2.5 Equipment Classes

Commercial refrigeration equipment can be divided into various equipment classes categorized by physical characteristics that affect the efficiency of the equipment. Most of these characteristics affect the merchandise that the equipment can be used to display, and how that merchandise can be accessed by the customer. Key physical characteristics are the operating temperature, the presence or absence of doors (i.e., closed cases or open cases), the type of doors used (i.e., transparent or solid), the angle of the door or air curtain (i.e., horizontal, semivertical, or vertical) and the type of condensing unit (i.e., remote or self-contained). The following list shows the key physical characteristics of commercial refrigeration equipment that DOE identified in its Framework document:

1. Operating Temperature
   - Medium temperature (38 °F, refrigerators)
   - Low temperature (0 °F, freezers)
   - Ice-cream temperature (-15 °F, ice-cream freezers)
2. Door Type
   - Equipment with transparent doors
   - Equipment with solid doors
   - Equipment without doors
3. Orientation (air-curtain or door angle)
   - Horizontal
   - Semivertical
   - Vertical
4. Type of Condensing Unit
   - Remote condensing
   - Self-contained

An alternate organization of equipment classes for commercial refrigeration equipment was proposed by ARI during the Framework comment period. ARI organized classes by equipment family (broad groups of covered equipment that have similar geometric characteristics), condensing unit type, and operating temperature. The equipment families ARI identified are:

- vertical without doors (air-curtain angle of 0 to 10° from the vertical),
- semivertical without doors (air-curtain angle of 10 to 80° from the vertical),
- horizontal without doors (air-curtain angle of 80 to 90° from the vertical),
- vertical with doors,
- horizontal with doors, and
- service over-counter.

One equipment family proposed by ARI, "service over-counter," was not included in the DOE organization of equipment classes and is unique in that it is designed to display products, but access to the products is from the backside of the cabinet. This equipment is designed to merchandise products for which access is typically provided only to sales personnel. DOE feels that this equipment family is necessary, as this type of equipment provides a different utility to the end-user than any of the other proposed classes.

As with DOE's equipment class organization, ARI's organization differentiates equipment by operating temperature. In addition to the three temperatures proposed by DOE (medium, low, and ice cream), ARI proposed a third temperature category: an "application" temperature. ARI explained that the application temperature category would allow manufacturers to test equipment at some temperature other than the three proposed by DOE, for models that could not be tested at one of those temperatures.

DOE examined the shipment data provided by ARI (see section 3.2.6) to determine the relative magnitude of equipment that operates at an application temperature compared to equipment that operates at one of the three temperatures proposed by DOE. Excluding equipment for which EPACT 2005 amended EPCA to set standards (self-contained commercial refrigerators and commercial freezers with doors), there were 170,949 units of remote condensing and self-contained equipment shipped in 2005 (shipments of commercial refrigerator-freezers were not reported, but are considered very small). Of the total shipments, only 1.7 percent were self-contained and remote condensing equipment that operate at 45°F, 20°F, 10°F, or -30°F (application temperatures), and 98.3 percent were of self-contained and remote condensing equipment that operate at 38°F, 0°F, or -15°F. By far, the application temperature with the largest number of units shipped is the 45°F category (typically "wine chillers"), and these were predominately remote condensing equipment. There were 1,834 units of remote condensing wine chillers shipped in 2005. Comparatively, in 2005 there were 85,001 units of remote condensing refrigerators that operate at 38°F.

DOE's test procedure for commercial refrigeration equipment, (see chapter 2) requires that all equipment, including equipment designed to operate at application temperatures, be tested at one of the three rating temperatures: 38°F for refrigerators, 0°F for freezers, and -15°F for ice-cream freezers. Given the relatively low shipment volumes of equipment that operates at application temperatures, as well as DOE's understanding that some of this equipment already can operate and be tested at one of the standard rating temperatures and that manufacturers might be able to redesign other equipment in relatively minor ways to have these capabilities, DOE believes this requirement will not place an unreasonable burden on manufacturers. In addition, if necessary, manufacturers could seek waivers from the DOE test procedure, pursuant to 10 CFR 431.401. For these reasons, DOE does not intend to develop separate standards for equipment that operates at application temperatures.

DOE is proposing to organize its equipment classes in a manner similar to ARI, and used the six ARI equipment families as a starting point to develop its list of equipment classes. The "vertical with doors" equipment class and the "horizontal with doors" equipment class were split into two each based on having either transparent doors or solid doors. Table 3.2.9 shows the eight commercial refrigeration equipment families DOE is proposing.

**Table 3.2.9 Commercial Refrigeration Equipment Families**

| Equipment Family | Designation | Description |
|---|---|---|
| Vertical Open | VOP | equipment without doors and an air-curtain angle greater than or equal to 0° and less than 10° |
| Semivertical Open | SVO | equipment without doors and an air-curtain angle greater than or equal to 10° and less than 80° |
| Horizontal Open | HZO | equipment without doors and an air-curtain angle greater than or equal to 80° |
| Vertical Closed Transparent | VCT | equipment with hinged or sliding transparent doors and a door angle less than 45° |
| Vertical Closed Solid | VCS | equipment with hinged or sliding transparent doors and a door angle greater than or equal to 45° |
| Horizontal Closed Transparent | HCT | equipment with hinged or sliding solid (opaque) doors and a door angle less than 45° |
| Horizontal Closed Solid | HCS | equipment with hinged or sliding solid (opaque) doors and a door angle greater than or equal to 45° |
| Service Over Counter | SOC | equipment with sliding or hinged doors intended for use by sales personnel and fixed or hinged glass for displaying merchandise |

Within each of these eight equipment families are equipment that can have one of two condensing unit types and one of three operating temperatures. The condensing unit type has a significant impact on utility and energy use, and can be either remote condensing (RC) or self-contained (SC). Remote condensing equipment is typically more efficient than self-contained because of the use of large, multiplex compressor rack systems that feed multiple pieces of equipment. Remote condensing equipment cannot be easily relocated, due to the refrigerant piping required, whereas self-contained equipment is more mobile, requiring only an electrical outlet for operation.

The operating temperature of the equipment also has a significant impact on utility and energy use, and can be medium (M), low (L) or ice-cream (I), representing a rating temperature (or IAT) of 38 °F, 0 °F, or -15 °F, respectively (± 2 °F). Because different types of merchandise require different temperatures (e.g., chilled and frozen), operating temperature is a necessary distinction. The larger temperature differences and thermodynamic behavior of refrigerants means that equipment with lower operating temperatures runs less efficiently than equipment with higher operating temperatures.

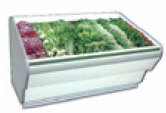
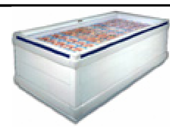
For open cases, vertical represents an air-curtain angle of <10° from the vertical, semivertical represents an air-curtain angle of ≥10° and <80° from the vertical, and horizontal represents an air-curtain angle of ≥80° from the vertical. DOE could not identify an existing industry definition of air-curtain angle, but developed a preliminary definition for consideration. DOE is considering defining air-curtain angle as “the angle between a vertical line and the line formed by the points at the center of the discharge air grille and the center of the return air grille, when viewed in cross-section.”

For closed cases, vertical represents a door angle of <45° from the vertical, and horizontal represents a door angle of ≥45° from the vertical. DOE did not receive stakeholder feedback on how to define the door angle for equipment with doors, but is considering defining door angle as "the angle between a vertical line and the line formed by the plane of the door, when viewed in cross-section."

Using all combinations of equipment families, operating mode and temperature, 48 equipment classes are possible, as illustrated in Table 3.2.10. However, self-contained equipment with doors that operate at a medium temperature, low temperature, or both, already had standards established in EPACT 2005. Therefore, these ten equipment classes are not included in this rulemaking and are indicated by asterisks in Table 3.2.10.

DOE also developed a lettering system to simplify discussion of equipment classes. The lettering designation for a particular equipment class consists of the lettering abbreviations for the equipment family, operating mode and temperature, separated by periods. A complete list of equipment classes with lettering designations is shown in Table 3.2.10, organized by family, operating-mode, and temperature.

## Table 3.2.10  Commercial Refrigeration Equipment Classes

| Equipment Family | Equipment Family Designation | Equipment Family Image | Operating Mode Designation | Temperature Designation | Equipment Class Designation |
|---|---|---|---|---|---|
| Vertical Open | VOP |  | RC | M (38°F) | VOP.RC.M |
| | | | | L (0°F) | VOP.RC.L |
| | | | | I (-15°F) | VOP.RC.I |
| | | | SC | M (38°F) | VOP.SC.M |
| | | | | L (0°F) | VOP.SC.L |
| | | | | I (-15°F) | VOP.SC.I |
| Semivertical Open | SVO |  | RC | M (38°F) | SVO.RC.M |
| | | | | L (0°F) | SVO.RC.L |
| | | | | I (-15°F) | SVO.RC.I |
| | | | SC | M (38°F) | SVO.SC.M |
| | | | | L (0°F) | SVO.SC.L |
| | | | | I (-15°F) | SVO.SC.I |
| Horizontal Open | HZO |  | RC | M (38°F) | HZO.RC.M |
| | | | | L (0°F) | HZO.RC.L |
| | | | | I (-15°F) | HZO.RC.I |
| | | | SC | M (38°F) | HZO.SC.M |
| | | | | L (0°F) | HZO.SC.L |
| | | | | I (-15°F) | HZO.SC.I |
| Vertical Closed Transparent | VCT |  | RC | M (38°F) | VCT.RC.M |
| | | | | L (0°F) | VCT.RC.L |
| | | | | I (-15°F) | VCT.RC.I |
| | | | SC | M (38°F) | VCT.SC.M* |
| | | | | L (0°F) | VCT.SC.L* |
| | | | | I (-15°F) | VCT.SC.I |
| Vertical Closed Solid | VCS |  | RC | M (38°F) | VCS.RC.M |
| | | | | L (0°F) | VCS.RC.L |
| | | | | I (-15°F) | VCS.RC.I |
| | | | SC | M (38°F) | VCS.SC.M* |
| | | | | L (0°F) | VCS.SC.L* |
| | | | | I (-15°F) | VCS.SC.I |
| Horizontal Closed Transparent | HCT |  | RC | M (38°F) | HCT.RC.M |
| | | | | L (0°F) | HCT.RC.L |
| | | | | I (-15°F) | HCT.RC.I |
| | | | SC | M (38°F) | HCT.SC.M* |
| | | | | L (0°F) | HCT.SC.L* |
| | | | | I (-15°F) | HCT.SC.I |
| Horizontal Closed Solid | HCS |  | RC | M (38°F) | HCS.RC.M |
| | | | | L (0°F) | HCS.RC.L |
| | | | | I (-15°F) | HCS.RC.I |
| | | | SC | M (38°F) | HCS.SC.M* |
| | | | | L (0°F) | HCS.SC.L* |
| | | | | I (-15°F) | HCS.SC.I |
| Service Over Counter | SOC |  | RC | M (38°F) | SOC.RC.M |
| | | | | L (0°F) | SOC.RC.L |
| | | | | I (-15°F) | SOC.RC.I |
| | | | SC | M (38°F) | SOC.SC.M* |
| | | | | L (0°F) | SOC.SC.L* |
| | | | | I (-15°F) | SOC.SC.I |

* These equipment classes have standards established by EPACT 2005 and are therefore not covered under this rulemaking.

### 3.2.6 Shipments

As part of its comments on the Framework Document (ARI, No. 7 Exhibit B at p. 1), ARI submitted annual shipment data by equipment class for its member companies. DOE understands that these data do not include the entire industry, since not all major manufacturers are represented by ARI.[c] However, because these data cover the vast majority of the remote condensing equipment sold, and because no other detailed data were available, the ARI shipment data became the basis of DOE's analysis.

Table 3.2.11 shows 2005 annual shipments for each category of commercial refrigeration equipment by equipment class. The ARI data included shipments for equipment that operates at an "application" temperature (e.g., wine chillers that operate at 45°F and freezers that operate at -30°F). However, DOE only considered shipments of equipment at the three temperatures considered in this rulemaking (38°F, 0°F, and -15°F; see section 3.2.5). The shipments of equipment that operate at one of these three temperatures constitute approximately 98 percent of the shipments reported by ARI.

[c] Most notably, True Manufacturing, which DOE understands has a large market share of self-contained equipment with doors and ice-cream freezers.

**Table 3.2.11 Air-Conditioning and Refrigeration Institute Shipments of Commercial Refrigerators and Freezers by Equipment Class**

| Equipment Family | Equipment Family Designation | Operating Mode Designation | Temperature Designation | Equipment Class Designation | ARI Shipments** |
|---|---|---|---|---|---|
| Vertical Open | VOP | RC | M (38°F) | VOP.RC.M | 38743 |
| | | | L (0°F) | VOP.RC.L | 0 |
| | | | I (-15°F) | VOP.RC.I | 0 |
| | | SC | M (38°F) | VOP.SC.M | 6512 |
| | | | L (0°F) | VOP.SC.L | 0 |
| | | | I (-15°F) | VOP.SC.I | 0 |
| Semivertical Open | SVO | RC | M (38°F) | SVO.RC.M | 29552 |
| | | | L (0°F) | SVO.RC.L | 0 |
| | | | I (-15°F) | SVO.RC.I | 0 |
| | | SC | M (38°F) | SVO.SC.M | 9750 |
| | | | L (0°F) | SVO.SC.L | 0 |
| | | | I (-15°F) | SVO.SC.I | 0 |
| Horizontal Open | HZO | RC | M (38°F) | HZO.RC.M | 4541 |
| | | | L (0°F) | HZO.RC.L | 14278 |
| | | | I (-15°F) | HZO.RC.I | 0 |
| | | SC | M (38°F) | HZO.SC.M | 838 |
| | | | L (0°F) | HZO.SC.L | 1738 |
| | | | I (-15°F) | HZO.SC.I | 0 |
| Vertical Closed Transparent | VCT | RC | M (38°F) | VCT.RC.M | 2767 |
| | | | L (0°F) | VCT.RC.L | 38483 |
| | | | I (-15°F) | VCT.RC.I | 0 |
| | | SC | M (38°F) | VCT.SC.M* | 43374* |
| | | | L (0°F) | VCT.SC.L* | 2472* |
| | | | I (-15°F) | VCT.SC.I | 1898 |
| Vertical Closed Solid | VCS | RC | M (38°F) | VCS.RC.M | 49 |
| | | | L (0°F) | VCS.RC.L | 2 |
| | | | I (-15°F) | VCS.RC.I | 43 |
| | | SC | M (38°F) | VCS.SC.M* | 4* |
| | | | L (0°F) | VCS.SC.L* | 4202* |
| | | | I (-15°F) | VCS.SC.I | 470 |
| Horizontal Closed Transparent | HCT | RC | M (38°F) | HCT.RC.M | 0 |
| | | | L (0°F) | HCT.RC.L | 15 |
| | | | I (-15°F) | HCT.RC.I | 0 |
| | | SC | M (38°F) | HCT.SC.M* | 724* |
| | | | L (0°F) | HCT.SC.L* | 0* |
| | | | I (-15°F) | HCT.SC.I | 9056 |
| Horizontal Closed Solid | HCS | RC | M (38°F) | HCS.RC.M | 37 |
| | | | L (0°F) | HCS.RC.L | 0 |
| | | | I (-15°F) | HCS.RC.I | 0 |
| | | SC | M (38°F) | HCS.SC.M* | 39761* |
| | | | L (0°F) | HCS.SC.L* | 4109* |
| | | | I (-15°F) | HCS.SC.I | 0 |
| Service Over Counter | SOC | RC | M (38°F) | SOC.RC.M | 9312 |
| | | | L (0°F) | SOC.RC.L | 9 |
| | | | I (-15°F) | SOC.RC.I | 0 |
| | | SC | M (38°F) | SOC.SC.M* | 1108* |
| | | | L (0°F) | SOC.SC.L* | 0* |
| | | | I (-15°F) | SOC.SC.I | 0 |

* These equipment classes have standards established by EPACT 2005 and are therefore not covered under this rulemaking.
**Source: ARI, No. 7 Exhibit B at p. 1.

### 3.2.6.1 Appliance Magazine Data

*Appliance Magazine* publishes historical and forecasted shipments of refrigerated display cases, which are shown in Table 3.2.12 and Table 3.2.13. As mentioned earlier, *Appliance Magazine* describes the data as representing refrigerated display cases but does not provide a precise definition of the equipment. It is unclear what types of equipment this term covers– whether it is equipment that is self-contained or remote condensing, or equipment with doors or without doors. For this rulemaking, only the self-contained equipment without doors and all remote condensing equipment are applicable.

**Table 3.2.12 Historical Shipments of Refrigerated Display Cases**

| Year | Unit Shipments |
|---|---|
| 1996 | 316,500 |
| 1997 | 324,000 |
| 1998 | 302,625 |
| 1999 | 340,453 |
| 2000 | 347,262 |
| 2001 | 175,000 |
| 2002 | 183,300 |
| 2003 | 191,549 |
| 2004 | 185,000 |
| 2005 | 170,000 |

Source: *Appliance Magazine*, *53rd Annual Statistical Review*, May 2006.

**Table 3.2.13 Statistical Forecasts of Refrigerated Display-Cases Shipments**

| Year | Unit Shipments |
|---|---|
| 2007 | 181,000 |
| 2008 | 185,000 |

Source: *Appliance Magazine*, *54th Appliance Industry Forecasts*, January 2006.

It is unclear what is responsible for the sharp decline in unit shipments between 2000 and 2001 reported by A*ppliance Magazine*. A similar decline is reported in other market literature, followed by an increase in shipments predicted by 2008.[21] It is believed that some fraction of the observed decline in shipments is the result of a general slowdown in the U.S. economy in the second and third quarter of 2001. Financial reports by CRE manufacturers discuss depressed investment and uncertainty in the retail food industry during the period from 2000 to 2005 as contributing factors to low sales of commercial refrigeration equipment. There may also be other explanations including possible changes in what equipment is included in "refrigerated display cases" by *Appliance Magazine*.

### 3.2.6.2 Current Industrial Reports

The U.S. Census Bureau's Economic Census of Manufacturing Industry Series and its Current Industrial Reports (CIRs) publish statistics on the quantity and value of shipments for those companies with shipments over $100,000 in value.[22,23] There are eight categories for display cabinets and display cases, including “reach-ins”. These are sub-divided into reach-in, closed display, and open display. As is evident from the tables provided below, the data reported in the CIRs are not complete (i.e., shipments data are not provided for most sub-categories).[d] The data also indicates some very large changes in the value of shipments between 1992, 1997 and 2002.

Table 3.2.14 shows shipment data for open refrigerated display cases, which include both self-contained units without doors and remote condensing units without doors. It is not possible from Table 3.2.14 to determine which shipments are for self-contained units and which are for remote condensing units as the census data reports these together in all reported data. Only the self-contained open refrigerated display cases and remote condensing open refrigerated display cases are applicable in this rulemaking.

**Table 3.2.14 Shipments of Open Refrigerated Display Cases (Remote Condensing and Self-Contained)**

| Type | Open or Closed | Temperature | Survey Year | Number of Companies with Sales over $100,000 | Shipment Quantity (1000's) | Shipment Value ($1000) |
|---|---|---|---|---|---|---|
| Display Case One Level | Open | Normal | 2002 | 6 | - | 89,622 |
| | | | 1997 | 13 | - | 140,259 |
| | | | 1992 | 12 | - | 142,268 |
| Display Case Multi Level | Open | Normal | 2002 | 9 | - | 341,472 |
| | | | 1997 | 11 | 58.6 | 258,310 |
| | | | 1992 | 9 | - | 151,760 |
| Display Case | Open | Frozen Food | 2002 | 6 | - | 11,538 |
| | | | 1997 | 7 | 20.4 | 90,213 |
| | | | 1992 | 8 | -- | 61,776 |

Source: U.S. Census, Current Industrial Reports, http://www.census.gov/cir/www/index.html; U.S. Census, Economic Census, Manufacturing Industry Series 1997, EC97M-3334D, http://www.census.gov/epcd/www/97EC31.HTM: U.S. Census, Economic Census, Manufacturing Industry Series 2002, EC02-31I-333415 (RV), http://www.census.gov/econ/census02/

Table 3.2.15 shows shipment data for closed refrigerated display cases, which include both self-contained units with doors and remote condensing units with doors. It is not possible from Table 3.2.15 to determine which shipments are for remote condensing units. Only the remote condensing closed refrigerated display cases are covered in this rulemaking.

[d] Shipments are not typically published for equipment with low shipments or shipments from only a small number of manufacturers in order to protect business sensitive information.

**Table 3.2.15 Shipments of Closed Refrigerated Display Cases (Remote Condensing and Self-Contained)**

| Type | Open or Closed | Temperature | Survey Year | Number of Companies with Sales Over $100,000 | Shipment Quantity (1000's) | Shipment Value ($1000) |
|---|---|---|---|---|---|---|
| Display Case | Closed | Normal | 2002 | 11 | - | 50,601 |
| | | | 1997 | 15 | - | 91,892 |
| | | | 1992 | 14 | - | 43,576 |
| Cabinet | Closed | Frozen Food | 2002 | 8 | - | 20,618 |
| | | | 1997 | 9 | - | 112,873 |
| | | | 1992 | 6 | | 38,171 |
| Other Display Cases | Not stated | Low Temp. | 2002 | 7 | - | 58,549 |
| | | | 1997 | 6 | - | 43,150 |
| | | | 1992 | 9 | 9.6 | 39,629 |

Source: U.S. Census, Current Industrial Reports, http://www.census.gov/cir/www/index.html; U.S. Census, Economic Census, Manufacturing Industry Series 1997, EC97M-3334D, http://www.census.gov/epcd/www/97EC31.HTM: U.S. Census, Economic Census, Manufacturing Industry Series 2002, EC02-31I-333415 (RV), http://www.census.gov/econ/census02/

For the data in Table 3.2.14 and Table 3.2.15, the following two commercial refrigeration equipment sub-categories are not included:

- Commercial reach-in refrigerators and reach-in vertical display cabinets for normal temperature applications (not intended for frozen foods, etc.) including self-contained and remote units.

- Commercial reach-in refrigerators and reach-in type vertical display cabinets for low-temperature applications, including self-contained and remote units.

Table 3.2.16 shows shipment data for commercial reach-in (vertical) cabinets (including self-contained units and remote condensing units). These cabinets can have either solid or glazed doors. It is not possible from Table 3.2.16 to determine which shipments are for remote condensing units and which shipments are for self-contained units. Only the remote condensing reach-in cabinets are covered in this rulemaking.

**Table 3.2.16 Shipments of Commercial Reach-In Cabinets (Remote Condensing and Self-Contained)**

| Type | Open or Closed | Temperature | Survey Year | Number of Companies with Sales Over $100,000 | Shipment Quantity (1000's) | Shipment Value ($1000) |
|---|---|---|---|---|---|---|
| Display Cabinets - Not for Frozen Foods | Not Specified | Normal | 2002 | 21 | 381.7 | 465,553 |
| | | | 1997 | 29 | - | 439,081 |
| | | | 1992 | 31 | 165.8 | 224,018 |
| Display Cabinet | Not Specified | Low Temperature | 2002 | 16 | - | 259,105 |
| | | | 1997 | 24 | - | 307,605 |
| | | | 1992 | 24 | 59.5 | 219,544 |

Source: U.S. Census, Current Industrial Reports, http://www.census.gov/cir/www/index.html; U.S. Census, Economic Census, Manufacturing Industry Series 1997, EC97M-3334D, http://www.census.gov/epcd/www/97EC31.HTM: U.S. Census, Economic Census, Manufacturing Industry Series 2002, EC02-31I-333415 (RV), http://www.census.gov/econ/census02/

In summary, although the U.S. Census Bureau Data contain some limited shipments data that would be useful for conducting technical analyses, not enough detail is provided in the data to provide specific assessments for shipments within each of the three primary categories covered in this rulemaking (i.e., commercial ice-cream freezers, self-contained commercial equipment without doors, and remote condensing equipment).

### 3.2.7 Equipment Lifetimes

DOE reviewed available literature and consulted with experts on commercial refrigeration equipment in order to establish typical equipment lifetimes. The literature and individuals consulted estimated a wide range of typical equipment lifetimes, as shown in Table 3.2.17.

Individuals with previous experience in the manufacture or distribution of commercial refrigeration equipment suggested a typical case life of 5 to 15 years. Experts in the field suggested that, while the equipment is typically robust in design, much of the equipment is replaced for cosmetic reasons during store remodeling (typically every 10 years or so). Consultation with one distributor suggested that U.S. tax depreciation schedules (which allow depreciation over a 5-year period for retail fixtures, including commercial refrigerators and commercial freezers)[24] are one driver for regular replacement of commercial refrigeration equipment in the United States.

Some literature reviewed suggested longer lifetimes of up to 20 years or more for commercial refrigeration equipment. Many of the studies cited here related to examination of environmental impacts of refrigerant emissions and therefore may not always clearly distinguish between the lifetime of the case and the lifetime of the compressor racks.[25] However, consultation with experts in the field suggested that smaller, independently owned grocery stores were more likely to keep equipment longer than larger chain stores.

Several industry experts suggested there is a significant used/refurbished equipment market. However, the size of the used market relative to the new market was not determined. Those consulted generally agreed that the salvage value of used equipment was very low compared to the initial purchase price. This is due to both cosmetic concerns and the custom nature of much of the equipment. Additionally, the difficulty in collecting used equipment of the same "look" for planned display case line-ups was cited as another reason for the low price of used equipment. A survey in the Pacific Northwest reported that for small, independent grocery stores (<20,000 square feet) and for independently owned convenience stores, the fraction of owners who would consider purchase of refurbished equipment was 25 and 16 percent, respectively. For larger, regional chains, this fraction was approximately 11 percent. None of the large grocery chains surveyed had plans to purchase refurbished equipment.

**Table 3.2.17 Estimates for Commercial Refrigeration Equipment Lifetimes**

| Life | Reference |
|---|---|
| 15 years | "New York Energy $martSM Program Cost-Effectiveness Assessment December 2004, NYSERDA[26] |
| 5-7 years (Large Chains) | Verisae[27] |
| 15 years (Smaller chains and independent grocers. May go up to 20 years) | Verisae[28] |
| 7-15 years | Mark Ellis & Associates[29], New Zealand Minimum Energy Performance Standards for Commercial Refrigeration Cabinets |
| 15 year | Foster-Miller (2001)[30] |
| 15-20 years | EPA (2001)[31] |
| 15 years | Arthur D. Little (ADL) (2002)[32] |
| 9-10 years (9 years with doors, 10 years without doors) | CEC 2004[33] |
| 5-15 years (Typical 10 years) | Hansen 2006[34] |
| 10 years | PG&E 2004[3] |
| 7-10 years (remote condenser)<br>8-12 years (self contained) | Intergovernmental Panel on Climate Change (IPCC) 2001[35] |
| 7 years | Fisher 1991[36] |

### 3.2.8 Market Performance Data

DOE conducted a survey of existing remote condensing refrigerated equipment from major manufacturers and compiled a performance database. The primary source of information for the database was equipment data sheets that were publicly available on manufacturers' websites. From these data sheets, equipment information such as total refrigeration load, evaporator temperature, lighting power draw, defrost power draw, and motor power draw allowed determination of calculated daily energy consumption (CDEC) according to the test procedure in ARI Standard 1200-2006, *Performance Rating of Commercial Refrigerated Display Merchandisers and Storage Cabinets.* Figure 3.2.2 through Figure 3.2.5 show CDEC values as a function of TDA for select remote condensing equipment classes. Figure 3.2.6 shows the relationship between air-curtain angle (measured from the vertical) and CDEC/TDA for the VOP.RC.M, SVO.RC.M, and HZO.RC.M equipment classes.

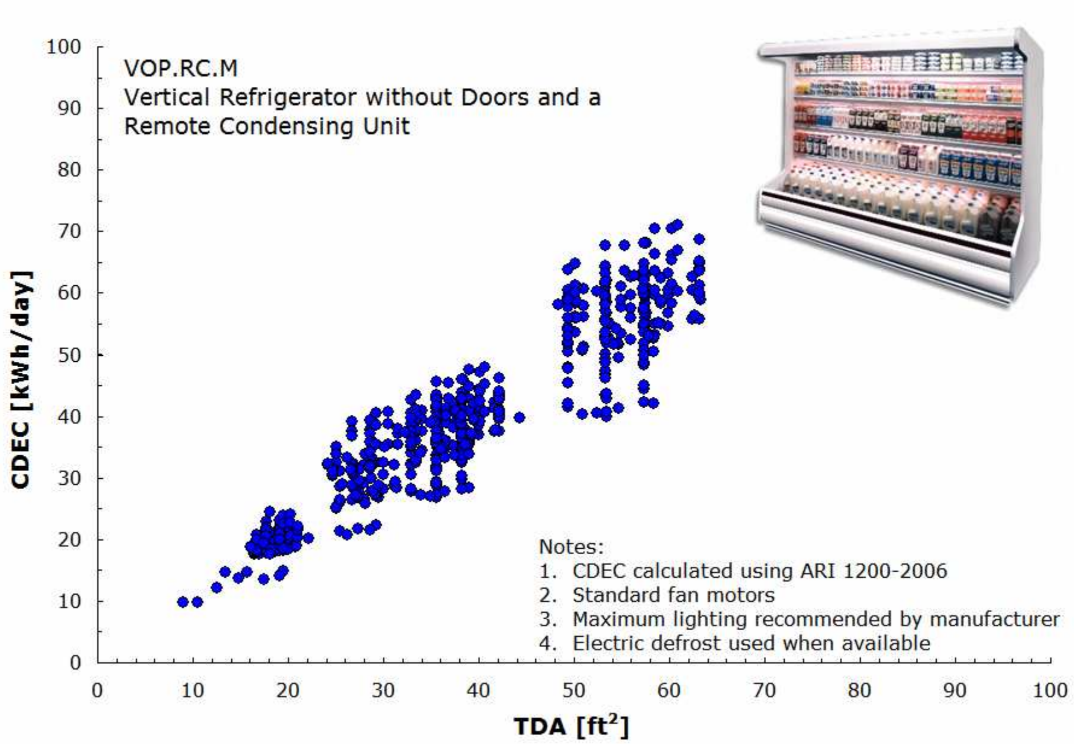



**Figure 3.2.2 Market Performance Data for the VOP.RC.M Equipment Class**

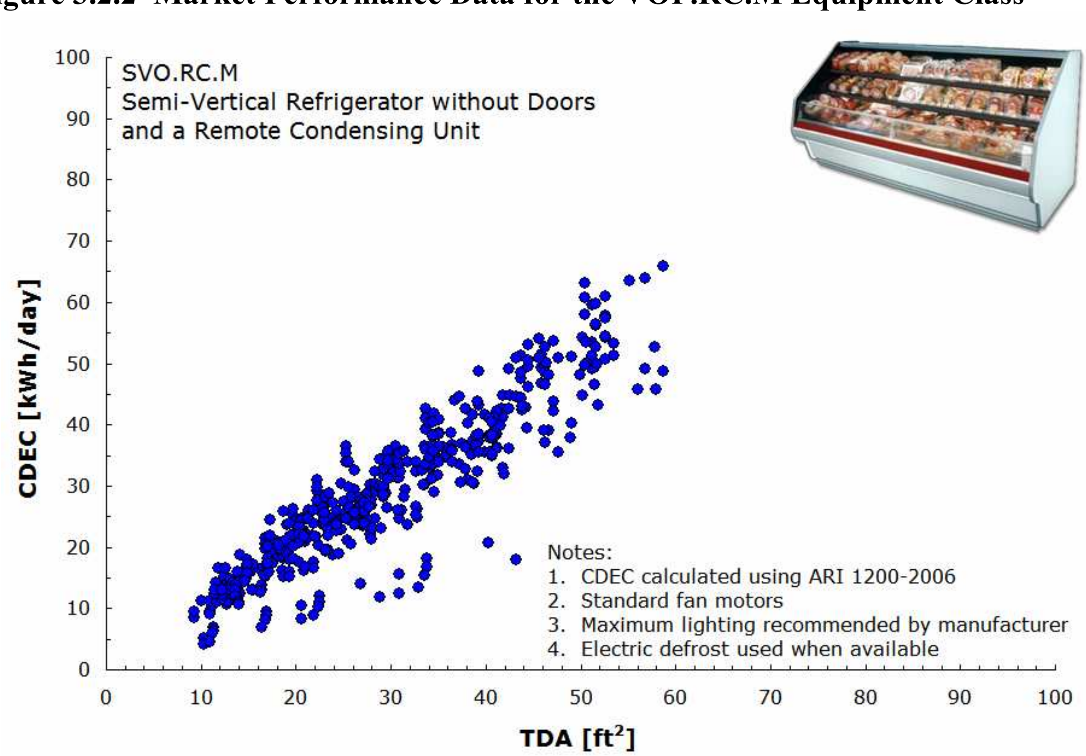



**Figure 3.2.3 Market Performance Data for the SVO.RC.M Equipment Class**

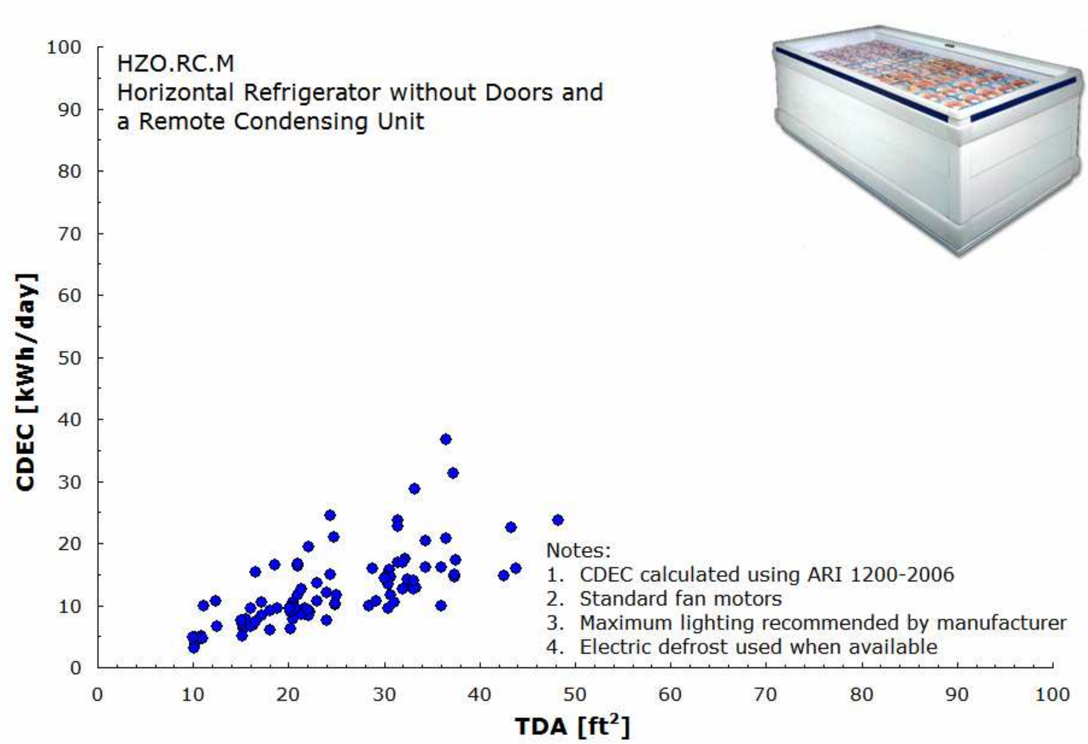



**Figure 3.2.4 Market Performance Data for the HZO.RC.M Equipment Class**

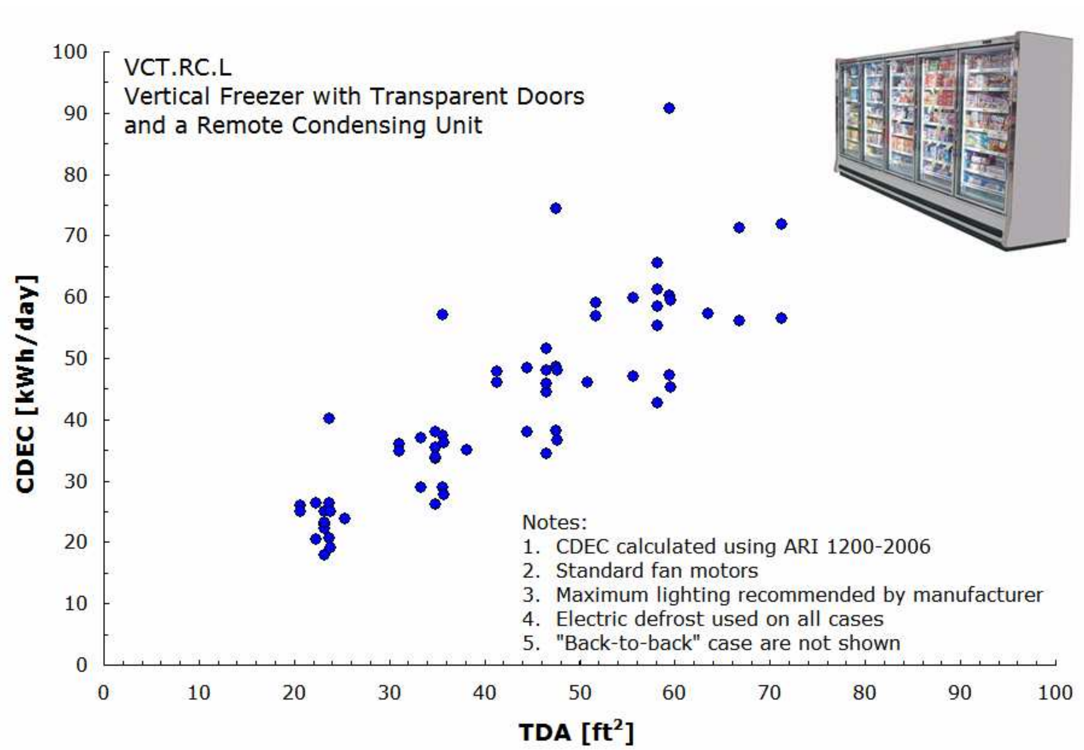



**Figure 3.2.5 Market Performance Data for the VCT.RC.L Equipment Class**

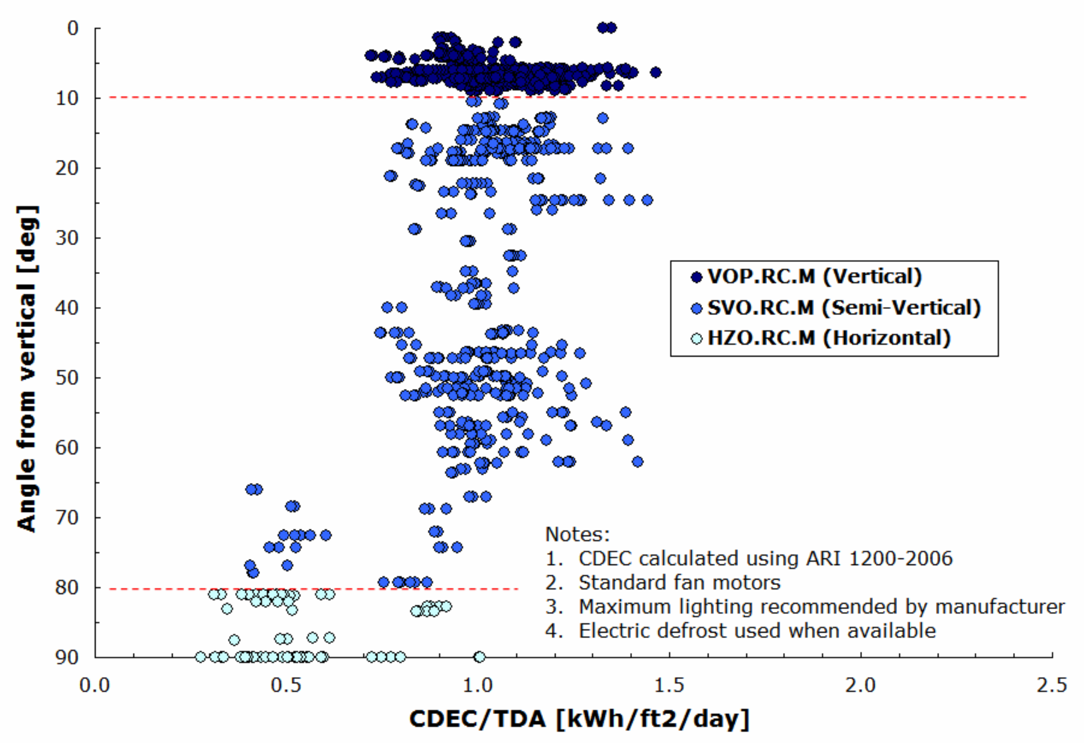



**Figure 3.2.6 Market Performance Data for the VOP.RC.M, SVO.RC.M, and HZO.RC.M Equipment Classes: Comparison of Air-Curtain Angles**

## 3.3 TECHNOLOGY ASSESSMENT

The purpose of the technology assessment is to develop a preliminary list of technologies that could potentially be used to improve the efficiency of commercial refrigeration equipment. The following assessment provides descriptions of technologies and designs that apply to all equipment classes; designs that apply to equipment without doors only; and technologies and designs that apply to self-contained equipment only.

### 3.3.1 Technologies and Designs Relevant to All Equipment Classes

The following technologies and designs are relevant to all equipment classes: higher efficiency lighting, higher efficiency ballasts, remote ballast location, higher efficiency expansion valves, higher efficiency evaporator fan motors, evaporator fan motor controllers, higher efficiency evaporator fan blades, increased evaporator surface area, low pressure differential evaporators, anti-sweat heater controllers, insulation increases or improvements, defrost mechanism, and defrost cycle control.

#### 3.3.1.1 Higher Efficiency Lighting

Commercial refrigeration equipment often includes lighting to illuminate the contents. Some commercial refrigeration equipment also includes an illuminated sign on the exterior of the unit. Higher-efficiency lighting leads to energy savings in two ways: less energy is used directly for lighting, and less heat energy is dissipated into the refrigerated case by the lamp. Efficiency in lighting is commonly measured as efficacy (lumens/watt), or the quantity of light output (lumens) per electrical energy input (watts, W).

Recently, the commercial refrigeration industry has been moving toward using T-8 fluorescent lighting in all cases. T-8 lighting is substantially more efficacious than T-12 lighting, and is predominantly used with electronic ballasts, which are more efficient than magnetic ballasts commonly used in T-12 lighting. The industry is also increasingly interested in T-5 lighting, although T-5 lighting systems are not significantly more efficacious than T-8 systems.

An even more recent trend is the use of light emitting diode (LED) technology. Although LEDs are less efficacious than fluorescent technology, they are more directional than linear fluorescent bulbs, allowing for comparable product illumination with less total wattage. There have been recent advancements in LED efficacy as well as the adoption of LED technology by large food retailers.[37] Research by the Lighting Resource Center indicates that lighting display cases using LEDs were found desirable by consumers. LEDs are predicted to steadily increase in efficacy and decrease in cost as technology improves.[38]

#### 3.3.1.2 Higher Efficiency Lighting Ballasts

Higher efficiency lighting ballasts reduce energy consumption by requiring less electrical power to operate, and by reducing waste heat generation, which contributes to case heat load.

Most illuminated display cases in supermarkets use fluorescent lighting with magnetic ballasts, which use inductance to modulate power flow to fluorescent lamps. Magnetic ballasts have significant electrical resistance losses. Electronic ballasts use solid state electronics to modulate power provided to fluorescent lamps. Electronic ballasts, which convert power at high frequency, have lower electrical resistance losses compared to magnetic ballasts which operate at line frequency. In addition, fluorescent lamps operate more efficiently at the higher frequency provided by electronic ballasts.

In addition to the direct reductions in electrical power consumption, heat generated by the lighting and the lighting ballast contribute to the case heat load. By increasing ballast efficiency, the compressor load is also reduced.

#### 3.3.1.3 Remote Lighting Ballast Location

Because lamp ballasts may be located remotely from the fluorescent lamps they power, they may be located within the display case cabinet but outside of the refrigerated space, reducing heat load and case energy consumption.

#### 3.3.1.4 Higher Efficiency Expansion Valves

Expansion valves are refrigerant metering devices whose purpose is to control the amount of refrigerant flowing to the evaporator coil. In doing so, they simultaneously decrease the temperature and pressure of the refrigerant, creating a cold liquid-vapor mixture. The low temperature of the refrigerant leaving the expansion valve creates the driving force to move heat out of the refrigerated space and into the evaporator.

The most basic type of expansion device is a capillary tube, which may be found in small self-contained commercial refrigeration equipment. The capillary tube is a long, thin piece of pipe that creates a pressure drop in the refrigerant through frictional losses. Capillary tubes must be sized to the particular application and cannot adjust for variations in load or ambient operating conditions. They are often oversized for worst-case conditions, and therefore may operate at reduced efficiency during normal operation.

The thermostatic expansion valve (TXV) is common in remote condensing commercial refrigeration equipment. This device uses an orifice to reduce the pressure of the entering refrigerant and a sensing bulb to monitor and maintain the temperature of the superheated vapor leaving the evaporator. Because the TXV allows for some degree of adjustment of refrigerant expansion, it may be somewhat more efficient than the capillary tube device under varying conditions. However, a TXV will likely not provide significant energy savings over a properly sized capillary tube under steady-state conditions.

The electronic expansion valve (EEV) is similar to the TXV, but uses an electronic control system to optimize refrigeration-system performance under all operating conditions. Because it does this with greater flexibility than that allowed by a TXV, an EEV theoretically allows for increases in energy efficiency under varying conditions. However, as with the TXV, an EEV will likely not provide significant energy savings over a properly sized capillary tube or over a TXV under steady-state conditions.

#### 3.3.1.5 Higher Efficiency Evaporator Fan Motors

Evaporator fan motors are fractional horsepower in size, are responsible for moving air across the evaporator coil, and typically run at one speed. The manufacturer will match the motor size and blade to the evaporator coil to meet the expected load on the case under most conditions. Higher efficiency evaporator fan motors reduce energy consumption by requiring less electrical power to generate motor shaft output power.

Electric motors operate based on the interaction between a field magnet and a magnetic rotor. In a brushed motor, the field magnets are permanent magnets and the rotor is an electromagnet; the situation is reversed in a brushless motor. The electromagnetic interactions between these two magnets cause the rotor to rotate.

The simplest type of electric motors—single-phase electric motors—suffer from a serious shortcoming. Single-phase motors only produce a rotating magnetic field when the rotor is rotating, and simply powering the electromagnet is therefore not sufficient to start such a motor. One of the most significant differences between different types of single-phase motors is the way in which they handle this start-up problem.

Nearly all inexpensive fan motors are of either the shaded-pole or the permanent split capacitor (PSC) variety, and the same is most likely true for standard commercial refrigeration equipment fan motors (fan motors not marketed as "high efficiency"). In both cases, the electromagnet consists of windings of electrical wire through which current is driven. In a shaded-pole motor, a portion of these windings is "shaded" by a copper loop. The interactions between the magnetic field generated by the shaded portion and that generated by the un-shaded portion induce rotation when the motor is powered. Because the imbalance between the shaded and unshaded portions of the magnet remains throughout operation, however, shaded-pole motors are inefficient, with typical motor efficiencies less than 20 percent.[39] Shaded-pole motors are, however, electrically simple and inexpensive.

In a PSC motor, a smaller, start-up winding is present in addition to the main winding. The start-up winding is electrically connected in parallel with the main winding and in series with a capacitor. At start up, the interactions between the magnetic field generated by the start up winding and that generated by the main winding induce rotation. Because of the capacitor, however, the current to the start-up winding is cut off as the motor reaches steady state. Because of this, PSC motors are more energy efficient than their shaded-pole counterparts, with motor efficiencies ranging from 50 to 70 percent. Like shaded-pole motors, PSC motors are produced in large quantities and are relatively inexpensive.[40] Commercial refrigeration equipment fan energy efficiency can be substantially improved by replacing shaded-pole motors, in the models that use them, with PSC motors.

A third type of electric motor, the electronically-commutated permanent magnet (ECM) motor (also known as the brushless permanent magnet motor), is more energy-efficient than either shaded-pole or PSC motors. ECM motors, which are sold in high volumes, are three-phase electric motors with efficiencies even greater than PSC motors. However, ECM motors can weigh about twice as much and are more expensive than equivalent PSC motors.

#### 3.3.1.6 Evaporator Fan Motor Controllers

Evaporator fan motor controllers allow fan motors to run at variable speed to match changing conditions in the case. During periods of frost build-up, fan motor power requirements increase; during the post-defrost period, power requirements decrease. Matching the fan speed to all conditions ensures more stable discharge air temperatures (and thus more stable product temperatures) and improves coil performance. Evaporator fan motor controllers would also allow the case to run more efficiently at different ambient humidity and temperature levels.

#### 3.3.1.7 Higher Efficiency Evaporator Fan Blades

High efficiency evaporator fan blades, or tangential evaporator fans, move air more efficiently, yielding energy consumption savings by reducing the required fan shaft power. The evaporator fans typically used in commercial refrigeration equipment have sheet metal blades. The blades are typically supplied by a fan blade manufacturer and mounted to the motor by the equipment manufacturer. These fan blades are not optimized for commercial refrigeration equipment. Evaporator fans may have lower efficiencies due to the higher required pressure drops, for which sheet metal fans are not well suited. Required fan shaft power could be reduced if the fan blades were optimized for each given application.

Tangential fans also provide an opportunity to decrease equipment energy consumption.[41] Tangential fans utilize a vortex builder to generate a uniform airflow over a large surface. This makes them better suited to evaporator and condenser fans, which need to distribute airflow over a large coil surface area. A single long tangential fan can meet the airflow requirements for an entire refrigerated cabinet, while requiring a single high-efficiency fan motor.

#### 3.3.1.8 Increased Evaporator Surface Area

The evaporator is a refrigerant-to-air heat exchanger composed of metals with high thermal conductivity such as aluminum and copper. It is responsible for evaporating and superheating the entering refrigerant liquid-vapor mixture while extracting heat from the air in the refrigerated space. The internal heat-exchanging surfaces in contact with refrigerant are commonly referred to as "refrigerant-side" while the external heat-exchanging surfaces in contact with the air are referred to as "air-side."

Depending on the requirements of the equipment, the evaporator will have a discharge air temperature (DAT) that can be up to 10°F colder than the desired temperature of the product. Because a temperature difference is necessary to drive heat from the air into the refrigerant, the saturated evaporator temperature (SET) must be considerably colder than the DAT. The magnitude of this driving force is directly related to the total refrigeration load and the thermal characteristics of the evaporator as shown in Equation 3.1:

$$DAT - SET = \Delta T = \frac{Q}{UA} \qquad \textbf{Eq. 3.1}$$

where
$Q$ is the total refrigeration load [Btu/h],
$U$ is the heat transfer coefficient of the evaporator [Btu/°F/ft$^2$],
$A$ is the area of the evaporator [ft$^2$], and
$\Delta T$ is the temperature difference between the discharge air temperature and evaporator temperature [°F].

Increasing the area of the coil will decrease the necessary $\Delta T$ and therefore decrease the SET. This results in an increased compressor energy efficiency ratio (EER) and lower compressor energy consumption.

Enhancements to the refrigerant-side surface area of the evaporator typically include rifled or diamond-pattern tubing and increased number of tube passes. Enhancements to the air-side surface area include increased fin pitch (decreased fin spacing), fin patterns (wavy or zig-zag), and increased numbers of tube passes.

Increasing the overall size of the coil in one or more dimensions without changing other aspects of the coil is another way to increase the area. However, most applications limit the amount of coil size increase. Most approaches to increasing the evaporator surface area also result in an increase in required fan motor power and an increase in refrigerant pressure drop.

#### 3.3.1.9 Low Pressure Differential Evaporators

Decreasing the air-side pressure drop of an evaporator coil allows for the use of lower-power evaporator fan motors. This requires reducing restrictions to the flow of air across the coil such as high fin pitch, and high numbers of tube passes. Large spaces between fins and tubes also reduce frost "bridging" which can completely block airflow through portions of the coil.

#### 3.3.1.10 Anti-Sweat Heater Controllers

Anti-sweat heating controllers match the on-time of anti-sweat heaters to the anti-sweat heating requirements imposed by the ambient humidity, reducing energy consumption when ambient humidity is low. Anti-sweat heating is necessary to prevent moisture condensation on surfaces of display cases, the temperatures of which can be below the ambient dew point.

Freezer-door gaskets are a typical example of such a surface. Anti-sweat heaters on freezer-door gaskets are typically always on, but the installation of controls that sense ambient humidity levels can turn off the heater when anti-sweat heating is not required, reducing electricity consumption. Such control requires measuring the local dew point or relative humidity, and measuring external surface temperatures. A particular heater can be turned on when the temperature of a particular surface falls below the dew point, or the heaters can be cycled with on-times increasing with dew point. Reducing anti-sweat heater on-time will also yield additional energy savings in case heat load reductions, since anti-sweat heaters contribute to case heat load.

In addition, it is possible that electric anti-sweat heaters could be replaced by a hot-gas line running around the doorframe. Although manufacturers have claimed that this is a difficult technology to implement, it has seen widespread and successful use in residential freezers.

#### 3.3.1.11 Improved or Thicker Insulation

Either increasing the insulation thickness or reducing insulation conductivity will reduce the energy consumption of commercial refrigeration equipment. Typical insulation thickness for refrigerated display cases ranges from 1.5 to 2 inches. Blow-in polyurethane foam is used for most cases. The impact of an increase in insulation thickness and insulation quality is limited for open cases by the fact that a large portion of the cooling load is due to infiltration.

Improved-technology polyurethane foam insulation has a reduced conductivity, reducing case heat load. The improvement is due mainly to the formation of smaller air cells within the foam insulation structure and better cell-size consistency. Use of the better foam would reduce case wall load, assuming no wall thickness change.

The importance of case volume suggests that technologies that would allow reduction in insulation thickness while maintaining thermal resistivity (R-value) would be of interest. Vacuum panels could provide such performance. Vacuum panels are airtight panels sealed with glass or plastic, which are evacuated to eliminate a conduction path. They are generally filled with supporting powder that prevents collapse of the external seal. Much work needs to be done to demonstrate the reliability of vacuum panels to show that they will perform for many years without leaking and losing their insulating value. Additionally, current-technology vacuum panels do not provide the necessary structural rigidity between sheet metal panels that is possible with foamed-in-place polyurethane insulation.

#### 3.3.1.12 Defrost Mechanism

As the air in the refrigerated space is cooled, water vapor condenses on the surface of the evaporator coil. In refrigerators and freezers, where the evaporator coil is below 32°F, this water freezes as it collects, forming a growing layer of frost. The frost reduces cooling performance by increasing the thermal resistance to heat transfer from the coil to the air, and by obstructing airflow. Both the method in which defrost is performed and control of the defrost cycle can lead to increased energy savings.

There are several methods available for defrosting the evaporator coil: off-cycle defrost, electric defrost, and hot-gas defrost. Off-cycle defrost involves shutting off refrigerant flow to the coil while leaving the evaporator fan running. This method is used where case air is above the freezing point of water and can be used to melt the frost. Electric defrost is used where the air temperature is not high enough to defrost the coil, and where defrost must occur quickly to prevent any significant rise in product temperature. Electric defrost involves melting frost by briefly turning on an electric resistance heater, which is in contact with or near the evaporator coil.

Hot-gas defrost is only applicable to remote condensing systems and involves the use of the hot compressor discharge gas to warm the evaporator from the refrigerant side. Electricity usage is reduced in comparison to the electric defrost method because available heat, which would otherwise be rejected in the condenser, is used. The hot gas defrost system requires more complicated piping and control than electric defrost. An additional drawback is the thermal stress inflicted upon the refrigerant piping by the alternating flow of hot gas and cold refrigerant.

#### 3.3.1.13 Defrost Cycle Control

Defrost-cycle control involves management of the initiation and termination of defrost cycles, and thereby the frequency and duration of defrost cycles. In the past, defrost cycles were completely scheduled, and initiation and termination were timer-controlled. Cycles were initiated at regular intervals, and terminated after a fixed amount of time. Cycle frequency and duration were then unrelated to actual frost conditions. Under timer control, the frequency of defrost cycles is determined by the amount of time the manufacturer expects it to take for a large frost layer to develop in the worst-case scenario, and the cycle duration long enough to ensure complete defrost in the worst-case scenario. Timer-based defrost can lead to unnecessarily frequent and long defrost cycles.

The current practice involves scheduled cycle initiation, determined by a timer, and demand-based cycle termination, determined by temperature sensors. Defrost cycles are still initiated at regular intervals, but are terminated when the coil temperature reaches a value indicating complete defrost. Partial demand-based defrost saves energy relative to fully scheduled defrost by limiting cycle duration, but cycle frequency can still be high.

Fully demand-based defrost would eliminate unnecessary defrost cycles. Two methods currently exist for carrying out demand-based defrost—measurement of cross-coil air-temperature drop and optical detection of frost buildup. Problems with these methods are associated with possible reduction of airflow for reasons other than coil frosting: dust collection, evaporator fan problems, varying product fill levels, and external flow disturbances.

### 3.3.1.14 Thermoacoustic Refrigeration

Thermoacoustic refrigeration is a technology that uses high-amplitude sound waves in a pressurized gas to pump heat from one place to another. A device consisting of a series of small parallel channels, referred to as a "stack," is fixed in place at a set location inside a resonator tube. In the case of a thermoacoustic refrigerator, external work is supplied by the standing sound wave in the resonator.

The longitudinal standing sound wave causes the gas particles to oscillate back and forth parallel to the walls of the stack. The alternating compression and rarefaction of the gas causes the local temperature of the gas to oscillate due to the adiabatic nature of sound waves. If the local temperature of the gas becomes higher than that of the nearby stack wall, heat is transferred from the gas to the stack wall. If the local temperature of the gas drops below that of the stack wall, heat is transferred from the wall to the gas.

Prototypes of thermoacoustic refrigerators have been demonstrated for commercial refrigeration applications. A prototype thermoacoustic refrigeration unit designed for an ice-cream freezer has been measured to be as efficient as the vapor compression unit it replaces. This technology is expected to improve in efficiency with further development of heat exchangers and other subsystems. It is also likely that efficiency in many applications could improve because thermoacoustic refrigerators are well suited to proportional control, where the cooling capacity can be continuously controlled so that the output can be adjusted accurately for varying load conditions. Although, this technology currently does not improve upon the efficiencies of conventional refrigeration technology, thermoacoustic refrigeration has the environmental benefit of being refrigerant-free.

### 3.3.1.15 Magnetic Refrigeration

Magnetic refrigeration utilizes the magneto-caloric effect where magneto-caloric materials like gadolinium absorb heat from their surroundings when entering a magnetic field, then reject heat to their surroundings when exiting a magnetic field. When magneto-caloric materials are circulated through magnetic fields and combined with heat exchangers to transfer heat, they can be used to remove heat from a refrigerated space and reject heat to the surroundings.

This refrigeration technology could be used in any possible application where cooling, heating or power generation is used today. Because of the early stage of development, many technical issues need to be addressed for this technology to be commercially viable.

### 3.3.1.16 Electro-hydrodynamic Enhanced Heat Transfer

Electro-hydrodynamic (EHD) enhanced heat transfer is the result of applying a high-voltage electrostatic potential field across a heat transfer fluid, such as a refrigerant or refrigerant mixture. The applied field destabilizes the thermal boundary layer, thereby producing better mixing of the bulk fluid flow and increasing the net heat transfer coefficient. This procedure appears to be more effective when applied to phase-change processes (e.g., boiling and condensation).

This phenomenon is typically used to electronically control the capacity of a heat exchanger by raising the applied voltage to increase the heat transfer. This can lead to improved efficiencies by using smaller capacity equipment, most of the time without EHD, and then utilizing the EHD effect during peak loads. EHD can replace, or work in conjunction with, enhanced surface heat exchangers. To use EHD, an electrical voltage (from a few volts to thousands of volts) is applied to the heat transfer device. However, because the heat transfer fluids are typically dielectric (of low electrical conductivity), even high voltages produce very little current. This low current helps keep the power (voltage x current) and the associated energy penalty low.

#### 3.3.1.17 Copper Rotor Motors

Making the critical components of an induction motor's rotor (e.g., conductor bars and end rings) out of copper instead of aluminum, which is the common current practice, improves the energy efficiency of the motor. The greater conductivity of copper results in lower resistance heating losses in the rotor and thus lower losses in the motor. Further improvements in the design and fabrication of copper motors, such as optimization of the steel laminations, could further increase the efficiency of copper motors over aluminum motors.

### 3.3.2 Designs Relevant Only to Equipment without Doors

The following design option is relevant only to equipment without doors: air-curtain design.

#### 3.3.2.1 Air-Curtain Design

Refrigerated display cases without doors allow consumers easy access to products while maintaining temperatures that ensure food safety. The absence of doors necessitates the use of a circulated air curtain to keep cold air inside the case. The refrigeration load for these cases is dominated by infiltration, or the entrainment of warm and moist air into the curtain. This infiltration adds both sensible and latent heat to the case, as well as depositing additional moisture on the evaporator coil, which must be removed through defrosting.

Improved air-curtain design is aimed at lessening the impact of infiltration by reducing the entrainment of warm ambient air. Making the air curtain flow as laminar as possible reduces entrainment. This involves configuring the plenum prior to the air curtain discharge grill to shape the velocity profile using a honeycomb grill to align the airstreams and encourage laminar flow. Improvements to the velocity profile and discharge air grill may enhance the performance of the air curtain and reduce the infiltration load.

### 3.3.3 Technologies and Designs Relevant Only to Self-Contained Equipment

The following technologies and designs are relevant only to self-contained equipment: higher efficiency compressors, liquid suction heat exchangers, increased condenser surface area, higher efficiency condenser fan motors, condenser fan motor controllers, and higher efficiency condenser fan blades.

#### 3.3.3.1 Higher Efficiency Compressors

Several technologies exist to increase the efficiency of commercial refrigeration equipment compressors. High efficiency reciprocating and scroll compressors, sometimes incorporating variable-speed motors, all have higher efficiencies than the traditional reciprocating compressors commonly used in commercial refrigeration equipment.

Scroll compressors compress gas in a fundamentally different manner from traditional compressors—between two spirals, one fixed and one rotating. High efficiency reciprocating compressors are as efficient, or more efficient, than scroll compressors. However, some drawbacks exist including noise, cost and reliability, compared to scroll compressors.

Variable-speed compressors are implemented through the use of an electronic control on the compressor motor, which allows the motor to operate at different speeds. Variable-speed compressors reduce energy consumption in three ways (but it should be noted that it typically increases efficiency over a broad operating range but does not inherently increase maximum efficiency at the compressor rating point):

1. When refrigerant flow is reduced during part-load operation, the condenser and evaporator (designed for full flow conditions) are more effective and thus more efficient. Temperature drops decrease, resulting in reduced pressure rise across the compressor, which also improves efficiency.

2. Close matching of load eliminates the cycling that occurs with single-stage compressors. Maintaining a constant pressure is more efficient because losses at higher pressure rise are greater than gains at lower pressure rise.

3. During the off-cycle, the pressure in the system equilibrates. At the intermediate pressure, refrigerant vapor will condense in the cold evaporator rather than the condenser. Essentially, some of the heat rejection load is rejected to the evaporator during this time, reducing overall system performance. Variable speed operation would eliminate or significantly reduce compressor off-time and the related inefficiencies.

#### 3.3.3.2 Liquid Suction Heat Exchangers

The goal of a liquid suction heat exchanger is to further cool the flow of liquid refrigerant entering the expansion valve using the flow of gaseous refrigerant leaving the evaporator, thus providing sub-cooling for the entering liquid by super-heating the exiting suction vapor. Hotter suction vapor is less susceptible to heat gains in the return piping to the compressor rack. The compressor work is increased, however, because the suction vapor has greater enthalpy. In addition, the possibility of compressor overheating problems brought on by the combination of increased compressor work and hotter vapor limits the use of this method in some situations. The possibility for these problems and the potential gains of liquid suction heat exchangers depend on the several factors, including evaporator temperature, type of refrigerant used, and system pressures.

#### 3.3.3.3 Increased Condenser Surface Area

Like the evaporator, the condenser is a refrigerant-to-air heat exchanger composed of metals with high thermal conductivity such as aluminum and copper. It is responsible for condensing and sub-cooling the entering refrigerant vapor while rejecting heat from the refrigerant to the ambient air.

Depending on the requirements of the equipment, the condenser will have a saturated condenser temperature (SCT) that is about 10°F warmer than the ambient air. As with evaporator coils, increasing the area of the condenser coil will decrease the necessary $\Delta T$ across the coil and therefore decrease the SCT, resulting in increased compressor efficiency (increased EER).

Enhancements to the refrigerant-side surface area of the condenser typically include rifled or diamond-pattern tubing and increased number of tube passes. Enhancements to the air-side surface area include increased fin pitch (decreased fin spacing), fin patterns (wavy or zig-zag), and increased numbers of tube passes.

Increasing the overall size of the coil in one or more dimensions without changing other aspects of the coil is another way to increase the area. However, most applications limit the amount of coil size increase in order to maintain overall equipment dimensions. Most approaches to increasing the condenser surface area also result in an increase in required fan motor power and an increase in refrigerant pressure drop.

#### 3.3.3.4 Higher Efficiency Condenser Fan Motors

Condenser fan motors are responsible for moving air across the condenser coil and typically run at one speed. The manufacturer will match the motor size and blade to the evaporator coil to meet the expected load on the case under most conditions. Higher efficiency condenser fan motors reduce energy consumption by requiring less electrical power to generate motor shaft output power. Condenser fan motors are generally of the same size and type as evaporator fan motors. See section 3.3.1.5 for a discussion of higher efficiency fan motor technology.

#### 3.3.3.5 Condenser Fan Motor Controllers

Condenser fan motor controllers allow fan motors to run at variable speed, to match changing conditions in the case. Matching the fan speed to all conditions improves coil performance. This allows the refrigeration system to run more efficiently at different ambient humidity and temperature levels. However, under steady-state conditions, there is no energy savings benefit with condenser fan motor controllers.

#### 3.3.3.6 Higher Efficiency Condenser Fan Blades

High efficiency condenser fan blades, or tangential condenser fans, move air more efficiently, yielding energy consumption savings by reducing the required fan shaft power. The condenser fans typically used in commercial refrigeration equipment have sheet metal blades. The blades are typically supplied by a fan blade manufacturer and mounted to the motor by the equipment manufacturer.  These fan blades are not optimized for commercial refrigeration equipment.  Required fan shaft power could be reduced if the fan blades were optimized for each given application.

Tangential fan also provide an opportunity to decrease commercial refrigeration equipment energy consumption.  Tangential fans utilize a vortex builder to generate a uniform airflow over a large surface.  This makes them ideal for evaporator and condenser fans that need to distribute airflow over a large surface area.  A single long tangential fan can meet the airflow requirements for an entire condenser, while only requiring one high-efficiency fan motor.

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